Atmospheric Measurement Techniques Discussions

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Reply on RC1

Chih-Chun Chou et al.

Author comment on "Validation of the Aeolus Level-2B wind product over Northern Canada and the Arctic" by Chih-Chun Chou et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-247-AC1, 2021

We thank the reviewers for their careful reading of the manuscript and comments, which helped us improve the study.

General comments:

The authors compare Aeolus winds with Ka-radar and radiosonde winds in Northern Canada in periods of the early phase during the first laser nominal flight model (FM-A; 2018-09 to 2018-10), the early phase during the second flight laser (FM-B; 2019-08 to 2019-09), and the mid-FM-B periods (2019-12 to 2020-01). They also compare Aeolus wind fields with ECCC-background and ERA5 reanalysis wind fields over the whole Arctic (poleward of 70ºN). Since direct wind observations are especially sparse in the Arctic, the topic is interesting and has important implication in evaluating the quality of Aeolus winds over the Arctic. However, the following major issues need to be improved.

- In order to use Aeolus wind data in numerical weather prediction models and to improve the data quality in newer processor versions, the systematic and random errors of Aeolus winds must be understood. As the purpose of this study is to evaluate the quality of Aeolus wind products over Northern Canada and the Arctic in comparison with several available observational products, the systematic and random errors of Rayleigh-clear and Mie-cloudy winds over these regions should be evaluated. Although the authors evaluated the random errors using Figs. 9–11, they did not evaluate the systematic errors.

Thank you for pointing out the need to clarify this aspect. Systematic errors were not fully examined in this work because bias-corrected Aeolus data were used in this study according to guidance provided by Rennie and Isaksen (2020). As stated in the paper, a bias offset of -1.35 ms^{-1} was added to the FM-A 2B02 Mie-cloudy winds, and a look-up table bias correction scheme was applied at ECCC to the FM-B 2B06/07 Mie-cloudy and Rayleigh-clear winds, as described in Rennie and Isaksen (2020). The FM-B 2B10 were bias corrected in the L2B processor, based on the M1 mirror temperature variations.

The following sentence is added in Line 62 for clarification: “We will focus on analyzing random errors instead of systematic errors since, as recommended for operational NWP practice, bias corrected Aeolus data is used in this study (see Sect. 2.1).”

Furthermore, instead of representing Aeolus, ECCC-B and ERA5 winds separately, Fig. 8 now shows the means and standard deviations of the *differences* between Aeolus and ECCC-B and ERA5. The means of the differences therefore reflect the remaining bias between the datasets after the dynamic bias correction has been applied. The associated paragraph describing Fig. 8 is also revised. Starting at line 394:

"We compare the distributions of the differences between the Aeolus wind measurement data and the ECCC-B and ERA5 data during fall 2018, summer 2019, and winter 2020 over the Arctic, as summarized in Fig. 8, which shows the bias and standard deviations of the differences between Aeolus HLOS winds and the ECCC-B HLOS winds, and ERA5 HLOS winds, and their zonal and meridional projections. The measurements are decomposed into Rayleigh (red) and Mie winds (black). They are further decomposed into ascending (indicated with upright triangles) and descending (inverted triangles) measurements. The results, with the bias (the mean values of these differences for the different sampling used) being smaller than 0.7 ms^{-1}, are consistent with our bias correction method. The distributions of the differences in the ascending and descending measurements do not show a significant difference. The discrepancies in the meridional projections of the HLOS winds are smaller because Aeolus picks up mostly the zonal component of the winds due to the direction of the LOS."

- My recommendation concerns bringing the findings of the paper into perspective with what is known from other literature, e.g., Belova et al. (2021), which conducts the validation of Aeolus HLOS winds against ground-based radar measurements in the Antarctica and northern Sweden.

Belova et al.'s (2021) findings on the systematic and random errors are summarized in line 72: "In related Arctic-based work, Belova et al. (2021) have found consistency between Aeolus winds and a ground-based radar situated in northern Sweden with insignificant biases between the two products (less than 1 ms^{-1}) and slightly increased random errors for Aeolus in the boreal summer, possibly due to sunlight scatter."

- During the mid-FM-B period (1 December 2019 to 31 January 2020), Aeolus L2B near real-time baseline products '2B07' were used. Please check https://aeolus-ds.eo.esa.int/oads/access/collection/L1B_L2_Products/tree.

This is fixed now. Thank you for pointing this out.

- The total number of measurements (N) and number of profiles (p) are important in calculating adjusted r-squared in Figs. 3, 4, and 5. Please give N and p of each site and period.

Thank you. The number of measurements (N) and number of profiles (p) are now provided in Table S1 to S3. Table S1 is for the validation at the sites, Table S2 for validation over the Canadian Arctic, and Table S3 for validation over the pan-Arctic.

- Figure 3d shows the scatter plot between Aeolus Rayleigh wind and Ka-band radar at Iqaluit. The number of comparison pairs is only 11. In my opinion, the sample size is too small. I suggest that the authors must perform the significance test.

Yes, we acknowledge that there are few applicable samples here. In order to assess significance, an F-test is performed, and all comparisons are at 99% confidence level, including the comparison between Aeolus and Ka-band radar at Iqaluit. We try to acknowledge more clearly the situation at line 311:

"Generally, the sampling for these radar measurements is highly limited, which tends to reduce the agreement compared to the other datasets. Nevertheless, the agreement on the variances between Aeolus and the Ka-band radar is at 99% confidence level using F-test. This analysis highlights the importance for programs such as CAWS to continue to provide ground-based radar measurements to ensure independent measurements of the winds for future DWL missions."

- What do you want to discuss using the HLOS winds projected onto the east-west and north-south directions in Figs. 7 and 8? What conclusions should the reader make from Figs. 7 and 8? In my opinion, the projected winds are not related to validation of Aeolus HLOS winds. The authors do not mention results obtained from Figs. 7 and 8 in Sect. 4. Please add some further explanations on that.

Thank you for these questions. Regarding the decomposition in Figures 7 and 8, the decomposition into different wind-component directions provides insight into understanding the meteorological conditions that the measurements are sampling, which might be helpful to better understand the dynamical characteristics of this data in both Aeolus and other products. We have slightly modified the text to better explain this analysis (line 375):

"Furthermore, some ascending and descending HLOS wind measurements cancel in the average owing to simply to the change of the angle of the LOS. To avoid this artefact and to add some insight into the wind features being measured, we also compare the projected HLOS wind vector into its zonal (positive to the east) and meridional (positive to the north) components. The distribution of the zonal-component of the HLOS winds is shown in Fig. 7e and g for Aeolus and ECCC-B HLOS winds. By doing this decomposition, the distributions for ascending and descending measurements are brought into better agreement (Fig. 7f). We also notice that the HLOS winds can provide some information about the vertical variation of the HLOS winds that are projected onto the zonal direction (Figs. 7e and g). For example, for Aeolus the projection of HLOS into the zonal direction for the stratosphere, UTLS, and troposphere are +11.00 ms^{-1}, +4.00 ms^{-1} and +1.00 ms^{-1} respectively for this measurement period and these values (and the standard deviations of their distributions, see the figure legend for values) agree very well with ECCC-B (and ERA5 – not shown). The distributions have mean values that are positive because the winds are mainly westerly over the Arctic in the winter."

Regarding Figure 8, first, please note that, as stated above under point 1, Fig. 8 is now showing the distributions of the differences between the products.

The following sentences are added in the discussion section (Line 495):

"In our analysis of the pan-Arctic region, we found an overall agreement by comparing the distributions of the HLOS winds, ascending and descending HLOS winds, and projections of HLOS winds onto east-west and north-south directions in different atmospheric layers (Fig. 7), and we also compared the distributions of the differences between Aeolus and ECCC-B and ERA5 (Fig. 8). Due to the angle of the HLOS, when comparing the distributions, separating the ascending with descending measurements helps avoid cancelling out part of the HLOS winds and projecting the HLOS winds on to zonal and meridional directions provides some insight on the vertical variation of the HLOS winds."

- Figs. 10 and 11 show spatial distributions of RMSD of Aeolus and ECCC-B vertical HLOS wind profiles. Figs. 10 and 11 are the most important result of the paper. The spatial distributions of RMSD show remarkable radial patterns. How do the authors explain these patters? Are these patterns due to interpolation of RMSD data to the grid points? The authors were not careful to ensure that the graphics all use similar color scales. Please use the same color scales for Figs. 10a–d and Figs. 11a–d. Similarly, please use the same color scales for Figs. 10e–h and Figs. 11e–h.

Thank you very much for highlighting this important issue and for the suggested improvements to the presentation. We found that the radial pattern was a spurious result arising from our choice of grids. We corrected this by transforming our data to the EASE (Equal-area scalable earth) grid, described at the NSIDC website (https://nsidc.org/data/ease). It is now corrected, and the following explanations are added in Line 436:

"Since the measurement density differs depending on the latitude, the RMSD of the profiles are calculated over nearly equal surface area, using the Equal-Area Scalable Earth (EASE) Grids (Brodzik et al., 2012). Each grid cell is around 104 km2 which is approximately the square of the along-path resolution of Aeolus Rayleigh winds."

Panels in Figs. 10 and 11 are now sharing the same colorbar.

- Lines 446-447: Why no significant improvement is seen here? The estimated HLOS errors of the 2B10 data are decreased compared to the 2B06 data (Figs. S2 and S3). I cannot understand the authors' explanation "because we have implemented a weekly updated dynamic bias correction to the near real time data". Please add some further explanations on that.

Thank you for pointing this out. It is true that the estimated errors are decreased in the reprocessed data. We wanted to make a point that the same improvement is not seen in the O-B statistics.

The following sentences are added for clarification in Line 470:

"The estimated observational errors have decreased compared to the 2B06 data (Figs. S1 and S2) since the bias due to the M1 mirror temperature dependence is updated on a daily basis and the dark current signals have been removed using improved quality control. However, we do not see the same improvement in the O-B statistics between 2B06 and 2B10 products over the Arctic region."

Specific comments

- Lines 23-24: "scattering from the solar background" should be revised to "the solar background radiation" or "the solar background noise". Thank you, fixed.
- Line28: "all cases" should be revised to "all three periods". Thank you, fixed.
- Line 28: "20%" should be revised to "5 to 40%". Thank you, fixed.
- Lines 68-69: Please clarify what is meant by "new technologies" and "cost-effective alternatives to atmospheric monitoring".

Thank you for the comment.

"this project serves to test new technologies and provide cost-effective alternatives to atmospheric monitoring over the northern regions”

is revised to

“this project serves to test the spaceborne DWL that provides alternative observational wind data to atmospheric monitoring over the northern regions”.

- Lines 78-80: “Section 3.1 describes the comparison during the early FM-A period (15 September to 16 October 2018) to ground-based measurements in Canada’s North, including the Iqaluit supersite and radiosonde stations over the Northern Canada.” However, I can see the comparison results during the early FM-B and mid-FM-B periods in Fig. 5. Please correct.

Thank you for pointing this out, the phrase “during the early FM-A period (15 September to 16 October 2018)” is removed.

- Line 82: “1 December to 31 January 2020” should be revised to “1 December 2019 to 31 January 2020”. Thank you, fixed.
- Line 107: An Aeolus observation can be regarded as an averaged value of a 90 km line for the Rayleigh winds and Mie winds until 5 March 2019, and as an averaged value of a 10 km line for the Mie winds after 5 March 2019 (Martin et al. 2021). Please correct.

Thank you for pointing this out. The passage (line 104) is revised to

“Prior to 5 March 2019, both Rayleigh and Mie winds were averaged to up to a horizontal resolution of 87 km. Recognizing that Mie scattering in cloudy air yields stronger returns than Rayleigh scattering in clear air, after 5 March 2019, the Mie wind product was provided at a finer horizontal resolution of 12 km.”.

- Lines 115-116: In my opinion, the phrase “winter 2020” is a bit misleading. I would advise to avoid this phrase and rather use “winter 2019–20”. Thank you, fixed.
- Line 127: Please give the values of the thresholds for L2B estimated HLOS errors of Rayleigh-clear winds and Mie-cloudy winds.

Thank you for the comment. The following passage is added in line 125:

“The thresholds for L2B estimated observation errors during the FM-A period are 4.5 ms-1 for the Mie winds and 6.6 to 11 ms-1 for the Rayleigh winds, depending on the pressure level, and 5 ms-1 for the Mie winds and 8.5 to 12 ms-1 for the Rayleigh winds during the early FM-B period. For more details, please refer to Rennie and Isaksen (2020).”

- Line 139: “ECCC-B background” should be revised to “ECCC-B”. Thank you, fixed.
- Lines 186-189 and 207-211: The authors downloaded the radiosonde data from http://weather.uwyo.edu/upperair/sounding.html. The vertical resolution of the radiosonde data is coarser than 15 m. The information of the geographical location and time at each level is not included in the radiosonde data. Is the balloon drift taken into account? Please given detailed data matching procedures between Aeolus and radiosonde.

Thank you for pointing this out. The raw radiosonde data is measured every 2 s, which results in a profile vertical resolution of 8-15 m. However, the data used from http://weather.uwyo.edu/upperair/sounding.html is the processed radiosonde data provided at standard pressure levels. It has a much coarser resolution than 15 m. The following passage is added in Line 191 for clarification:

“Vaisala RS92 radiosondes (Mariani et al., 2018) were launched twice daily (45 minutes before synoptic times 00 and 12 Coordinated Universal Time (UTC)). They measure vector wind profiles with a vertical resolution of roughly 15 m depending on ascent speed, up to about 30 km above ground level. The data used (available at http://weather.uwyo.edu/upperair/sounding.html) is the processed radiosonde data provided at mandatory and significant pressure levels (which has a coarser resolution than 15 m). It takes about two hours to reach 30 km altitude (around 10 hPa). The instrumental uncertainty for the wind speed is between 0.4 and 1.0 ms^{-1} and between 0.3 and 0.7 ms^{-1} for the zonal wind component (Dirksen et al., 2014). The error on the zonal wind component due to drift and elapsed time of the ascending balloon is between 0.5 and 1.0 ms^{-1} in the troposphere and UTLS (see Fig.5b in Laroche and Sarrazin, 2013). As a result, the total error for the zonal wind component from these sources of errors is between 0.6 and 1.2 ms^{-1}. Note that the radiosonde data are assimilated in the ECCC and ECMWF systems, which means that the ECCC-B and ERA5 errors are not independent of the radiosonde observation errors. The ECCC Whitehorse site, situated in a wide valley with large lakes, also has radiosondes that operate similarly to the ones at the Iqaluit.".

Section 2.5 on the data matching process and coincidence criteria is also revised. "For the ground-based validation, the criterion for coincidence of Aeolus overpasses is that the distance from the sites to the measurements be no more than 90 km (horizontal resolution of Rayleigh winds). Using this coincidence criterion, Aeolus overpasses are selected as targets for validation at Iqaluit three times a week at around 21:50, 11:15, and 22:00 UTC, and at Whitehorse twice a week at around 02:25 and 15:30 UTC. The Aeolus measurements are compared to the reanalysis and in-situ measurements that are available in the nearest time. Temporal sampling for each product is as follows: Aeolus overpasses at Iqaluit and Whitehorse are as mentioned above; reanalysis data is provided hourly, on the hour; radiosonde data is from launches at 00 and 12 UTC, with a two-hour time-of-flight to 30 km as mentioned above; Ka-band radar data is provided via 15-minute scans. For example, if Aeolus overpasses selected as a target for validation at the Iqaluit site at 11:15 UTC, since the reanalysis data is sampled hourly, the radiosondes are launched at 00 and 12 UTC, and the Ka-band radar at Iqaluit scans every 15 minutes, the Aeolus HLOS profile would be compared to the reanalysis data and radiosonde measurements at 12 UTC and to the nearest scan by the radar. On the other hand, if the overpass time is 02:25 UTC, the profile would be compared to the ERA5 data at 02 UTC, the radiosonde measurements at 00 UTC, and, again, the nearest scan by the radar.".

- Line 217: "overpasses Asia around 06 and 18 UTC" is error and needs to be corrected.

This sentence is removed, and the paragraph is revised as mentioned above.

- Figure 2: Please add y-axis title. Why are there two Rayleigh winds at the same altitude above 5 km in Fig. 2b. Similarly, why are there two Mie winds at about 8 km in Fig. 2a. Is this consistent with the temporal criterion described in lines 214-215. Why are the maximum altitudes of HLOS wind profile obtained from ECCC-B 15 km (20 km) in Fig. 2a (2b)? "at Iqaluit" should be added in the caption.

There were two Aeolus measurements at the same level due to the collocation criteria. Figure 2 is now revised and is only showing the nearest profile from Aeolus to the sites.

This is because the background values were provided at the observation locations. ECCC-B is linearly interpolated to Aeolus measurement locations and times.

The following passage is added in line 143 for clarification:

"The data used to compare with Aeolus winds in this paper is the assimilated data that is linearly interpolated to Aeolus measurement locations and times. For the linear interpolation between the model's grid points, the horizontal grid-spacing is 15 km and the vertical grid-spacing varies from approximately 100 m in the PBL to 1 km in the stratosphere (McTaggart-Cowan et al., 2019). The linear interpolation in time is between two consecutive model states, 15 min apart."

- Figure 3 and Line 249: Is "frequency distributions in percentage" correct? What are the color shading areas in the scatter plots (Figs. 3a-d)?

The "frequency distributions in percentage" is correct. They are shown in the panels above and to the right of the scatter plots.

Line 268: "Figures 3 and 4 show scatter plots between the different datasets with lines of best fit and their range," is added.

- Line 270: Is "The ERA5 shows somewhat slightly lower correlation" correct?

Table 1 is added. It shows the adjusted r-squared and slope of the fitted line for the in-situ comparison.

The paragraph in line 291 is revised to:
"Overall, the datasets show strong consistency. ECCC-B and ERA5 are highly mutually consistent (Table 1; with adjusted r-squared greater than 0.97) and therefore show similar consistency with Aeolus (Figs. 3a-b and 4a-b). It can be seen that Aeolus Mie winds are less consistent with ECCC-B, ERA5, and radiosondes at Iqaluit than the corresponding observations at Whitehorse and for the Rayleigh winds. One possible reason for this relates to the fact that the Mie channel samples winds in the lower atmosphere where winds are harder to assimilate or measure due to topography. Since Iqaluit is situated in tundra valleys with rocky outcrops that can cause increased variability in the wind field while Whitehorse is situated in large valleys with less wind variability due to topography, terrain effects might account for the difference in consistency. In addition, the overall range extent of the HLOS wind samples is between -25 to 25 ms^{-1} at Iqaluit and -45 to 45 ms^{-1} at Whitehouse and r-squared is sensitive to the range of data (note the denominator of the second term in Eq. (5)). Overall, Aeolus data show good agreement with these three datasets with adjusted r-squared greater than 0.8.".

- Figure 4: Figure 4 is exactly the same as Fig. 3. Please correct. Thank you, fixed.
- Figure 5: Why did the adjusted r-squared of Mie winds decrease with time? The authors should mention the decrease and discuss the reasons.

Thank you for the question. Please note that the range on the y-axis is from 0.7 to 1.0. The difference may look large on the plot, but the change is almost insignificant. The 99% confidence level on the adjusted r-squared is added on the figure. The range of the adjusted r-squared for Mie winds is almost overlapping between the seasons. The following paragraph is added in Line 337 for clarification:

"We also note a slight drop in consistency of the Mie winds for the mid-FM-B period, which took place in winter 2020: for instance, the adjusted r-squared and their 99% confidence intervals, between Mie winds and ECCC-B, are 0.920.03 during fall 2018, 0.910.01 during summer 2019, and 0.870.02 during winter 2020. This decrease in the consistency is almost insignificant."

- Line 321: "The reprocessed data has improved estimated errors and RMSD" should be revised to "The reprocessed data has improved estimated errors and RMSD over the excluded region". Thank you, fixed.
- Figure 6: Please add y-axis titles. "Aeolus L2B estimated error" should be revised to "Aeolus L2B estimated error of Rayleigh winds". Thank you, fixed.
- Line 335: "free troposphere (2-8 km)" should be revised to "free troposphere (T, 2-8

km)". Thank you, fixed.

- Line 336: "stratosphere (altitude greater than16 km)" should be revised to "stratosphere (S, altitude greater than16 km)". Thank you, fixed.
- Figure 7: Please add y-axis titles. Fig. 7. Figures. 7b and 7d do not use the same horizontal axis scale as Figs. 7f and 7h. Please correct. "70N" should be revised to "70ºN". "each level" should be revised to "each atmospheric layer". Thank you, fixed.
- Figure 8: Please add y-axis titles. Thank you, fixed.
- Figure 9: Please add (a), (b), (c), (d), (e), and (f) to the image. Thank you, fixed.
- Line 392: What do you mean with "more structure"? Please add some further explanations on that.

Thank you for the comment. The sentence in line 411 is revised to:

"Figure 9 shows that Aeolus data consistently has greater standard deviations than ECCC-B during all three periods and for both Rayleigh and Mie winds: its normalized standard deviations are typically within 1.05 to 1.40.".

- Line 433: "observation errors" should be revised to "estimated errors of Rayleigh winds". Thank you, fixed.

Technical corrections

- British or European English: For example, you use "16 October 2018" and "October 16^{th} 2018".
- Line 268: Fig. -> Figs.
- Line 345: Fig. -> Figs.
- Line 427: Fig. -> Figs.
- Line 428: Fig. -> Figs.
- Line 445: Fig. -> Figs.
- Line 469: Fig. -> Figs.

Thank you, they are fixed now.

Please also note the supplement to this comment:
https://amt.copernicus.org/preprints/amt-2021-247/amt-2021-247-AC1-supplement.pdf